ontario hydro
research division

To: Dr. D. Mills
Director of Research

REAL-TIME LIGHTNING LOCATION SYSTEM

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A network of wideband direction finders has been established throughout Ontario. These receivers pick up radiated fields from distant lightning strokes. The bearing and amplitude data is sent over telephone lines to a central computer. The computer calculates stroke position and amplitude by triangulation in real time and displays the results on remote graphics terminals. Lightning data for most of Ontario has been available to Ontario Hydro for two summers. This data has been used for tracking the movement of storms across Bruce-Milton 500 kV circuits and the 230 kV East-West Tie transmission line.

1.0 *INTRODUCTION*

In 1978, the Ontario Ministry of Natural Resources set up a small network of commercial lightning detection equipment, sold by an American company called Lightning Location and Protection (LLP). This network was used for managing the forest fire risk from lightning strokes in remote regions. The system met with wide acceptance and was eventually extended to include eleven direction finder (DF) units, a central position analyzer (PA) and several remote display processors (RDP).

Prior to 1984, Ontario Hydro relied mainly on observations of lightning using short-range instruments located at stations. There was limited interest in the further development of these units, either for portable use or for incorporation into a developing Power Systems Operations Division (PSOD) program of severe weather warning.

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In late 1984, a meeting of several interested parties was hosted by PSOD. The following groups were represented:

- Ontario Hydro Research Division - Electrical Research
- Ontario Hydro PSOD - Resource Utilization - Meteorology
- Environment Canada - Atmospheric Environment Service (AES)
- Ontario Ministry of Natural Resources (MNR) - Aviation and Fire Management Centre
- Bell Canada
- University of Toronto - Department of Electrical Engineering

At this meeting, Ontario Hydro expressed interest in using the existing MNR network data for the following purposes:

- Detection of Storm Movement across Transmission Facilities. Lightning is the most frequent cause of circuit breaker operations and interruptions; with good forecasts of storm activity, loads on important lines could be reduced from clear-weather limits. This would allow greater transmission capacity most of the time.
- Scheduling and Warning of Line Crews. Line crews are not allowed to work if lightning activity is noted in the vicinity; with real-time lightning data, crews could be safely and efficiently dispatched to deal with the problems that occur after lightning storms.
- Study of Lightning Currents. The choice of insulation levels on transmission lines depends on the expected stresses caused by lightning; the lightning location system measures the peak radiated magnetic field from the lightning currents, which is closely related to the current.
- Study of System Failures. Equipment breaks down from lightning activity; it also breaks down for other reasons. In order to separate the lightning-related failures from others, accurate lightning locations are needed.

Ontario Hydro and AES needed the existing MNR lightning data to improve their weather forecast accuracy. In turn, Hydro and AES could offer improved coverage and accuracy to MNR by operating DF sites in southern Ontario. Also, theoretical studies of lightning currents by the University of Toronto and the Research Division would, as a by-product, help to improve the location data. As a result of the common interests discovered at the meeting, a co-operative program for a province-wide LLP lightning detection network was established for 1985.

2.0 *CO-OPERATIVE LLP LIGHTNING PROGRAM*

Prior to the co-operative program, the Ontario Ministry of Natural Resources (MNR) operated an LLP system of eleven DFs, as shown in Figure 1. Triangulations were processed at the Aviation and Fire Management Centre in Sault Ste. Marie. The system was operated during the lightning season, from April to September every year. This required one full-time system manager with supporting staff, and the total telephone charges were $100 k per season. An extension to include a station at North Bay was planned for 1986.

In addition to the MNR network, there was a single LLP DF station operated at King City in southern Ontario by the Atmospheric Environment Service. This DF was used to study correlations between radar return echoes and lightning activity.

There was general agreement that the MNR Aviation and Fire Management Centre, located at Sault Ste. Marie, was the logical centre for operating the expanded system. The MNR staff are most qualified to support continuous system operation during the summer and were willing to share their existing facilities. At the same time, any additional expenses involved in system expansion would be covered by Ontario Hydro, with Research Division initially purchasing the equipment and PSOD funding the telephone line costs. The single DF site operated by AES at King City would also be tied into the network.

In 1985, two LLP DF units were purchased and installed by Research Division at Clinton and Collingwood. Also, RDP display units were purchased by PSOD and by the University of Toronto. Dedicated telephone lines were arranged by PSOD for continuous updating of the RDP units. The new system is described in more detail below. The southern Ontario network, as shown in Figure 2, was commissioned during the winter of 1985-86 and was placed on-line in March, 1986.

3.0 *DESCRIPTION OF EXISTING NETWORK*

Each DF consists of an electric field antenna and two orthogonal magnetic loops. Figure 3 shows a photograph of the magnetic field antenna, mounted on top of a tower of three wood poles. Figures 4 and 5 show the site arrangements at Clinton and Delphi Point. The electric field antennas are mounted on the roofs of the wooden instrumentation sheds. A buried trench holds cables for electrical supply and voice and data communication services. The sheds are heated by baseboard heaters and cooled by thermostatic fans.

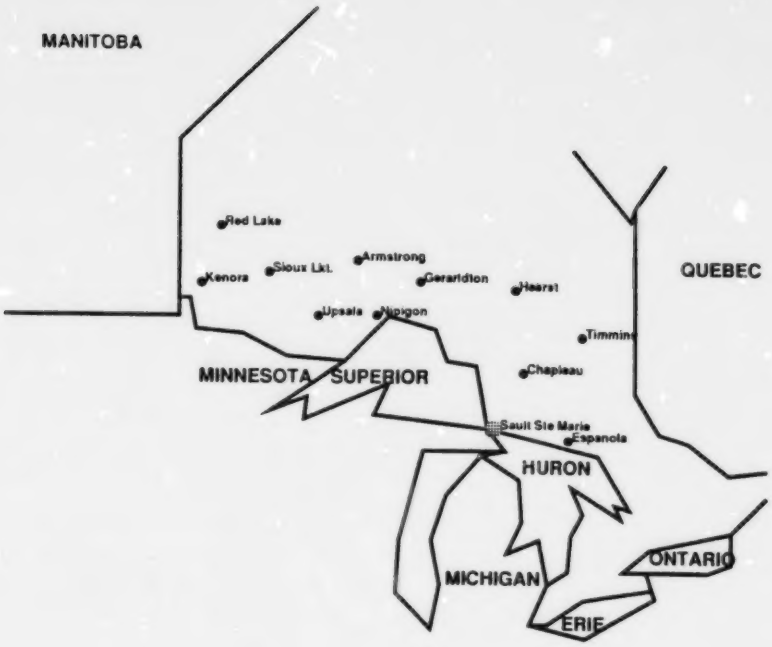

Figure 1
Ontario Ministry of Natural Resources
1985 LLP Lightning Detection Network

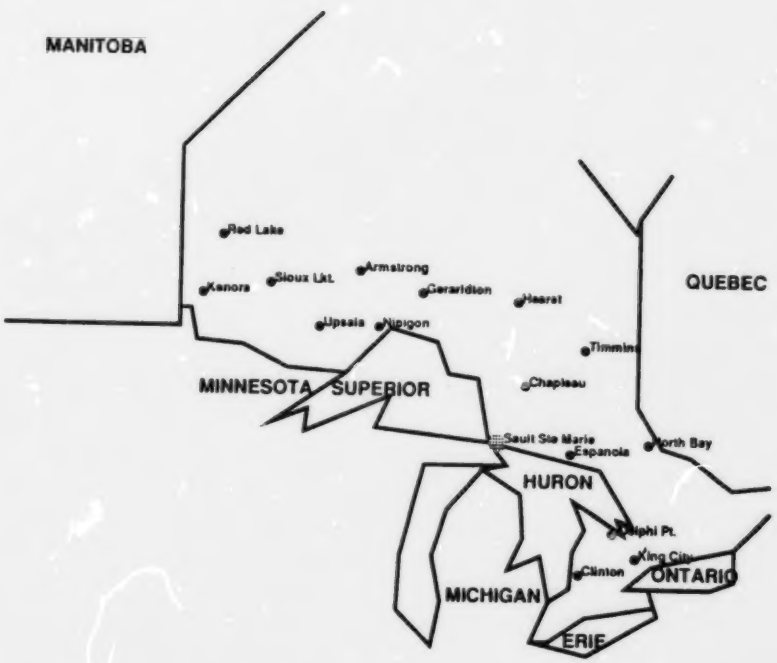

Figure 2
Co-Operative 1986 LLP Lightning Detection Network

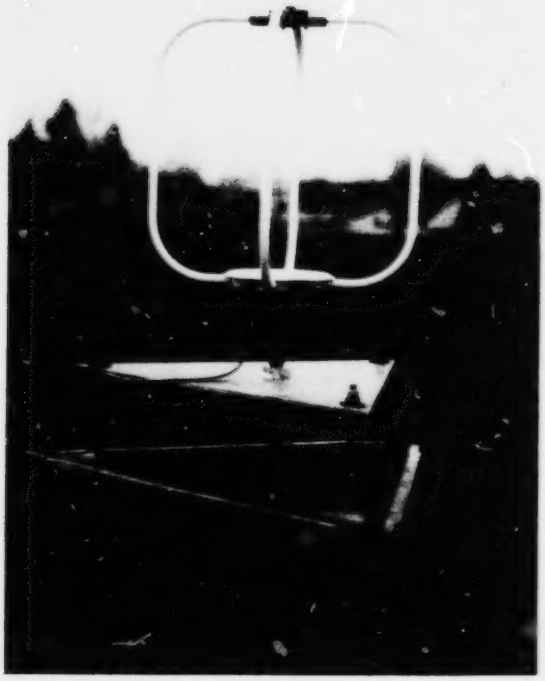

Figure 3
Magnetic Loop Antenna for Lightning Detection System

Figure 4
LLP Direction Finder Site at Delphi Point, near Collingwood

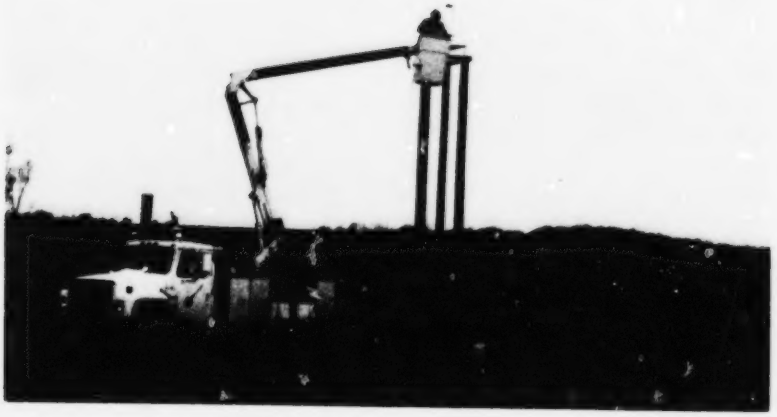

Figure 5
LLP Direction Finder Site at Clinton

The LLP instrumentation located in the sheds amplifies the signals from the antennas. Several waveform tests are then applied to ensure that the signals are cloud-to-ground lightning rather than impulse noise or cloud-to-cloud flashes. Acceptable waveforms are digitized and then converted to bearing and amplitude values. The DF observation is then transmitted along with a time and date code to the central computer via the leased data line and modem.

When the central position analyzer receives two or more DF observations that have the same time code, it can calculate the location of the stroke. This is done with the use of spherical geometry, because the curvature of the earth causes errors at distances beyond 200 km. Once an intersection of two bearings has been obtained, the radiated field is normalized to a common distance of 100 km to allow comparison with other stroke intensities.

The position analyzer sends out the analyzed stroke data to a number of remote display processors. These RDPs store a large number of flashes and display them on useful maps. The MNR maps, for example, show their operational regions; the Ontario Hydro RDP is programmed with their critical transmission lines. Against the background map, the progress of the storm is easily followed by changing the colour of the flash symbol at periodic intervals. For example, Figure 6 shows the movement of a storm across the East-West Tie line on July 24. The orange dots near Thunder Bay are individual negative flashes occurring in the time from 12:00 to 12:30. The large (+) marks indicate less-frequent, higher-amplitude positive flashes. All flashes in the next half hour are yellow, followed by green, blue, violet and red. An alert operator would reduce power transfer on the Tie line at the end of the orange period and would increase it again with some risk during the blue period. In Figure 7, a storm is seen to be building up over Lake Michigan and moving into the Bruce Transmission Corridor. Figure 8 shows the movement of a storm through the Toronto area. Figures 9 and 10 show examples of map displays that include the Bulk Electrical System transmission facilities.

The lightning position data is usually accurate to within 10 km. This makes the data suitable for rearrangement of power system configurations, but less useful for fault location based on individual strokes. The system errors have been studied extensively in co-operation with the University of Toronto and the Canadian Electrical Association, and are discussed briefly in the next Section.

4.0 *SYSTEM DETECTION EFFICIENCY AND ACCURACY*

Each DF can detect high-current lightning strokes as far as 500 km away. However, a good efficiency, defined as the ratio of strokes detected and actual number of strokes, is not achieved at this distance. At 400 km, only currents above 31 kA will be detected. Half of the flashes will have peak currents lower than this threshold, so the detection efficiency at 400 km will be only 50%.

Figure 6
Map of Lightning Activity near Marathon on July 24, 1986
The blue line is the 230 kV East-West Tie.
Each colour represents lightning in a 30-minute period.

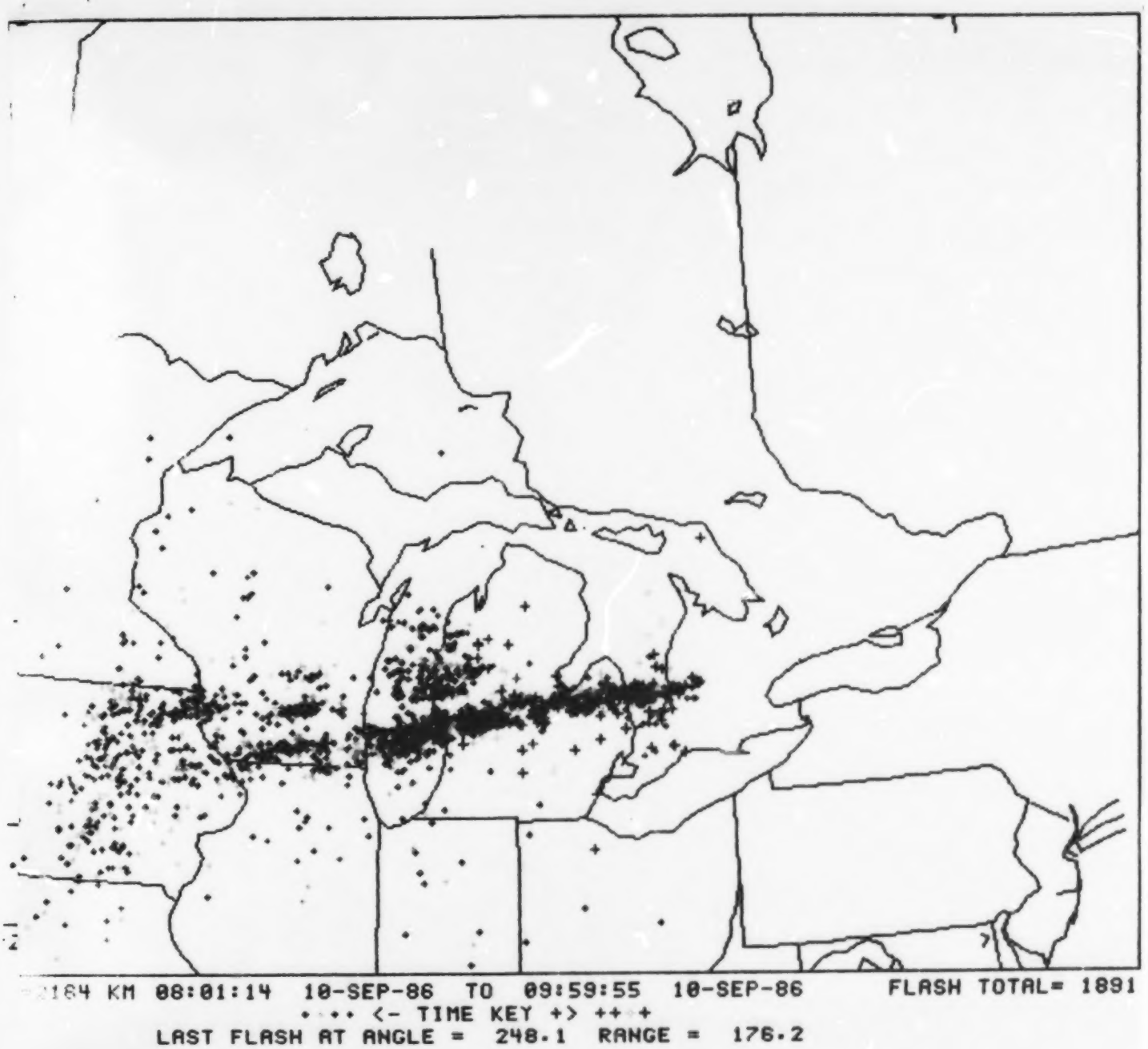

Figure 7
Map of Lightning Activity across Ontario, September 10, 1986
Each colour represents lightning in a 30-minute period.
Note the long-range detection capability of the system.

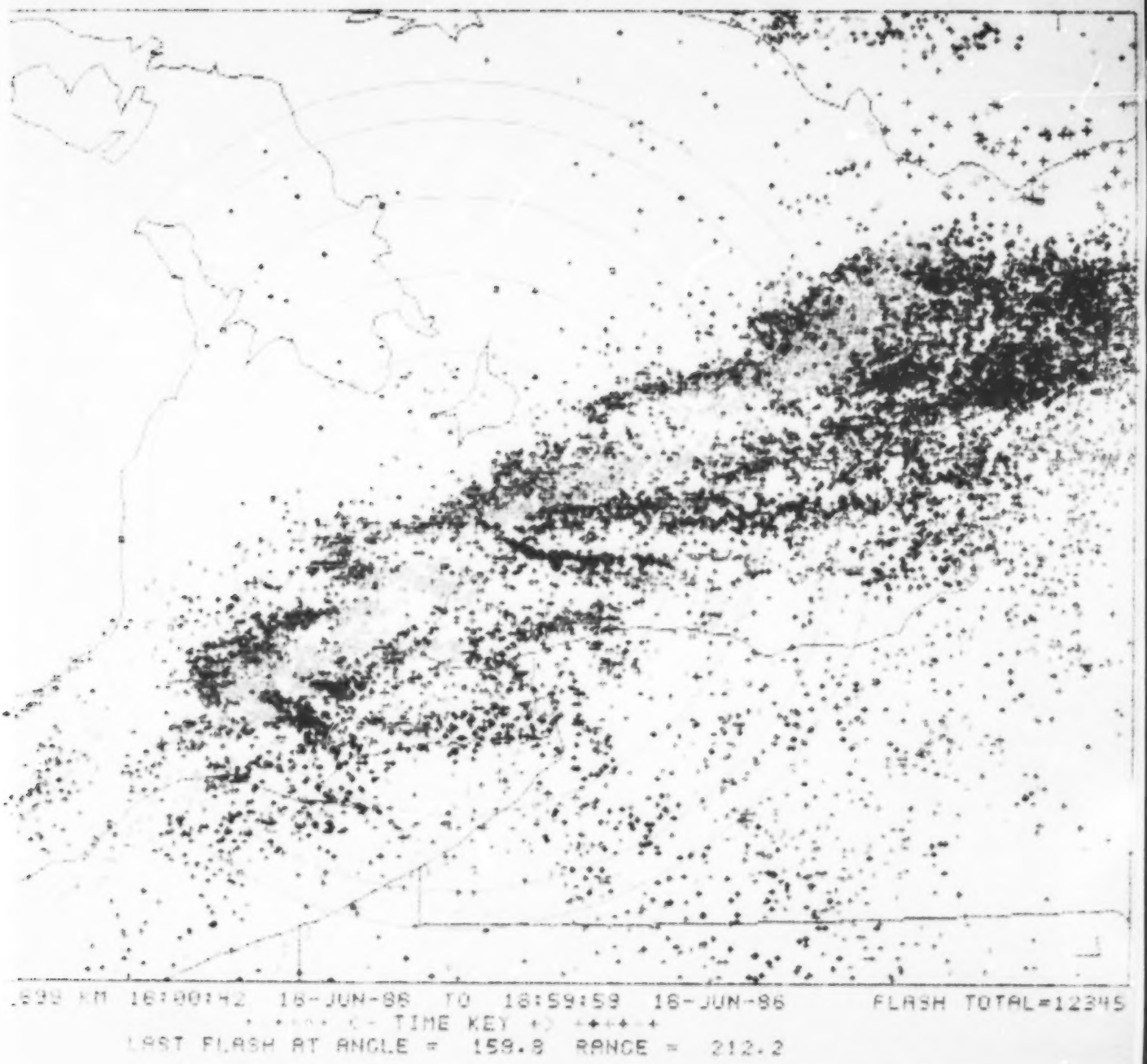

Figure 8
Map of Lightning Activity across Southern Ontario on June 16, 1986
Each colour represents lightning in a 30-minute period.

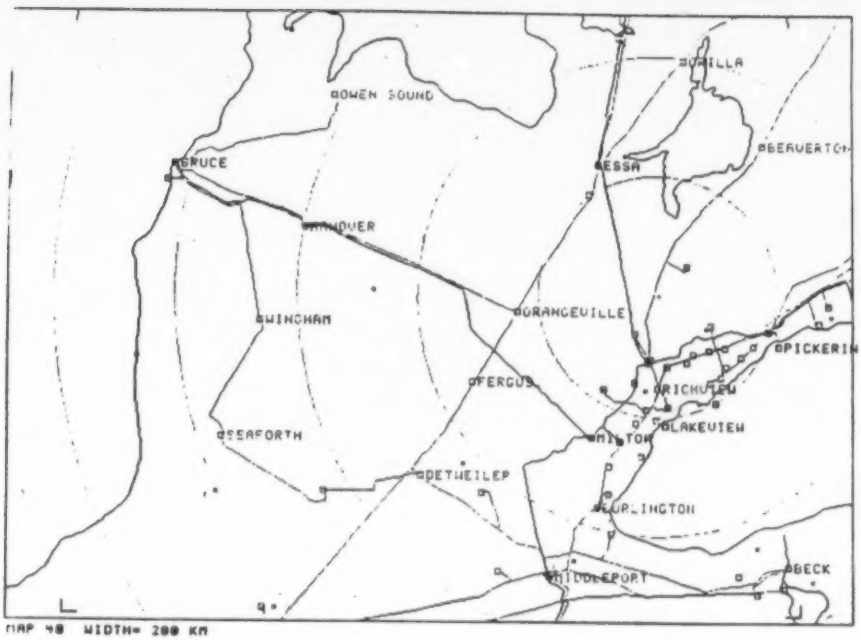

Figure 9
Detail Map of Bruce NGS - Milton Transmission Corridor

Figure 10
Detail Map of Toronto and Vicinity Transmission Facilities

The detection of a flash requires at least two DF observations. This means that the detection efficiency of a point in the network will depend on the distance of that point to the two closest DF sites. The composite detection efficiency throughout the system can, however, be calculated by computer. Figure 11 shows the efficiency for the Ontario LLP network as presently installed.

Many areas of the province already have an acceptable efficiency for detection of lightning activity. Improvements could be achieved by sharing data with LLP systems in neighbouring states and provinces, but this would require more processing power and considerably higher telecommunication costs. Additional DF sites within the province could also improve detection efficiency with somewhat lower cost. Figures 12-14 show the improvements in efficiency to be gained by adding stations at Simcoe, White River and Bancroft respectively.

One important area for research is the use of peak radiated field data for study of lightning currents. This has been done using LLP data from the summer of 1983. A detailed report on these studies will be issued at a later date, but several technical papers /1-5/ have already been published.

A second question for research involves the existence of systematic site errors. All direction-finding systems are subject to slight bearing and amplitude errors that vary with azimuth. For example, a DF will read 3 degrees too high to the north-west and 3 degrees too low to the south-west. The site errors can be identified and corrected with the use of additional observations, either by independent "ground truth" studies or by processing of flashes that are picked up by three or more DF stations. Work in this area is also proceeding.

5.0 *CONCLUSIONS*

Through a co-operative program involving several outside agencies, Ontario Hydro has gained access to a province-wide real-time LLP lightning location system. The lightning activity is displayed on suitable maps using a dedicated graphics terminal. The data is used immediately by PSOD to identify high-risk conditions that call for power system reconfigurations. Stored lightning data is also studied to identify possible damage locations, to improve system accuracy and to estimate peak lightning currents.

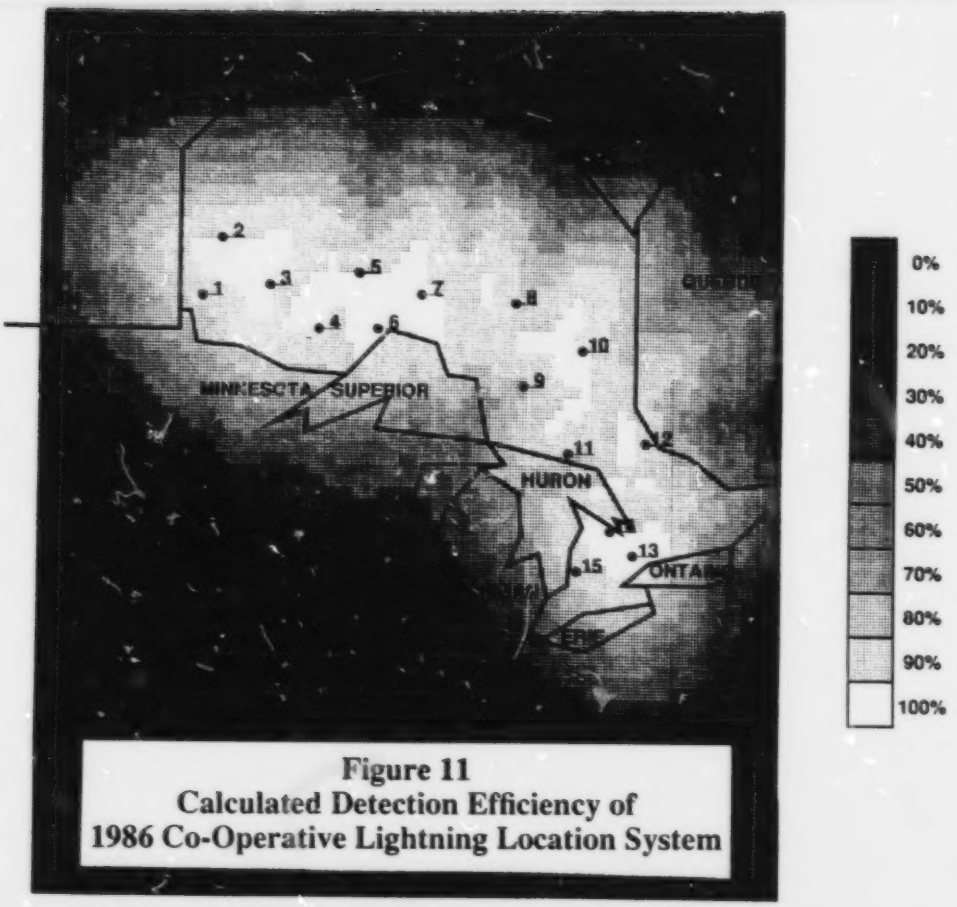

Figure 11
Calculated Detection Efficiency of
1986 Co-Operative Lightning Location System

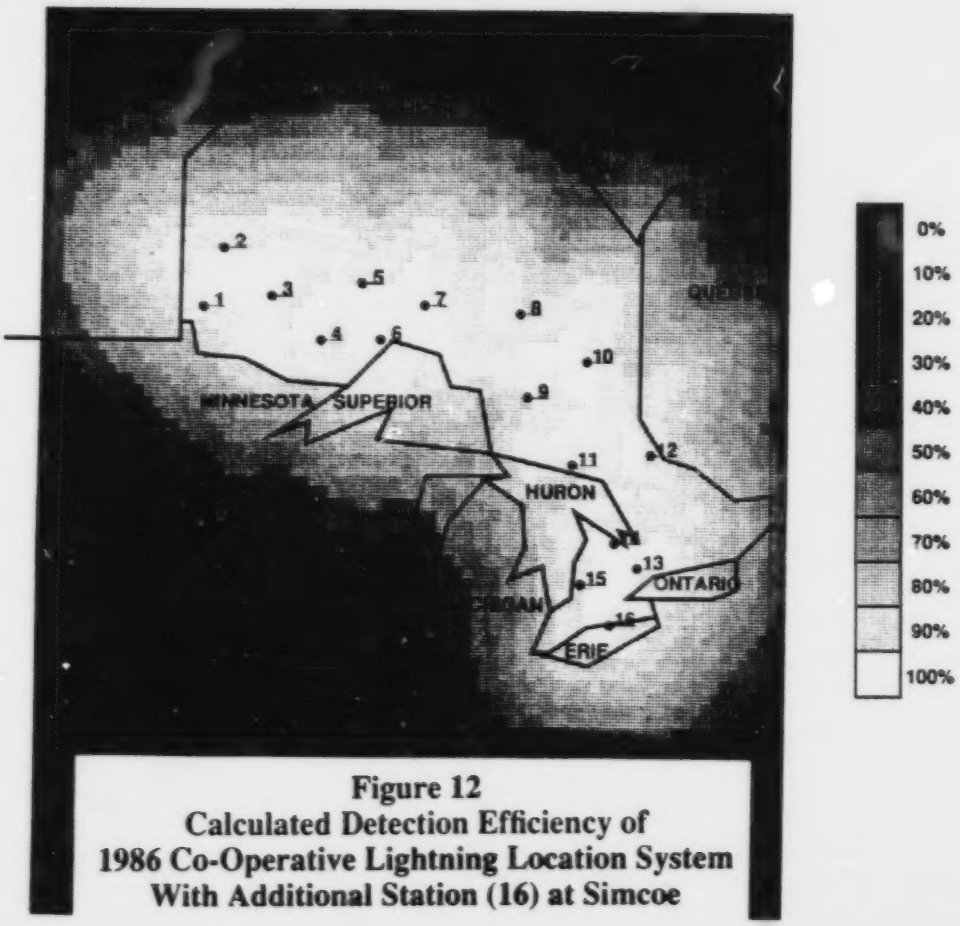

Figure 12
Calculated Detection Efficiency of
1986 Co-Operative Lightning Location System
With Additional Station (16) at Simcoe

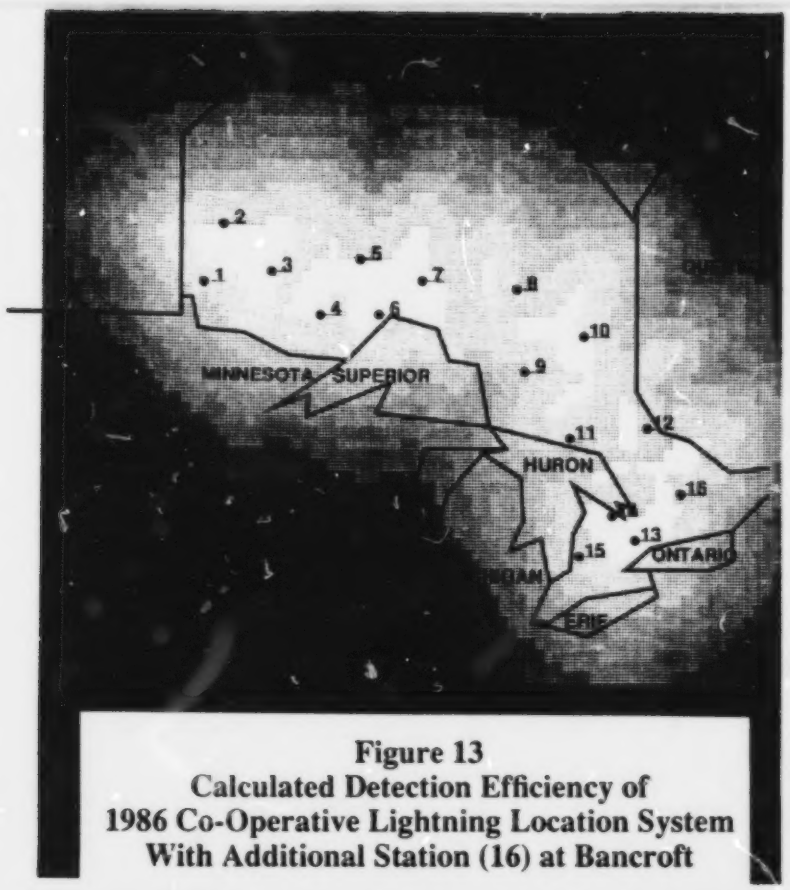

Figure 13
Calculated Detection Efficiency of
1986 Co-Operative Lightning Location System
With Additional Station (16) at Bancroft

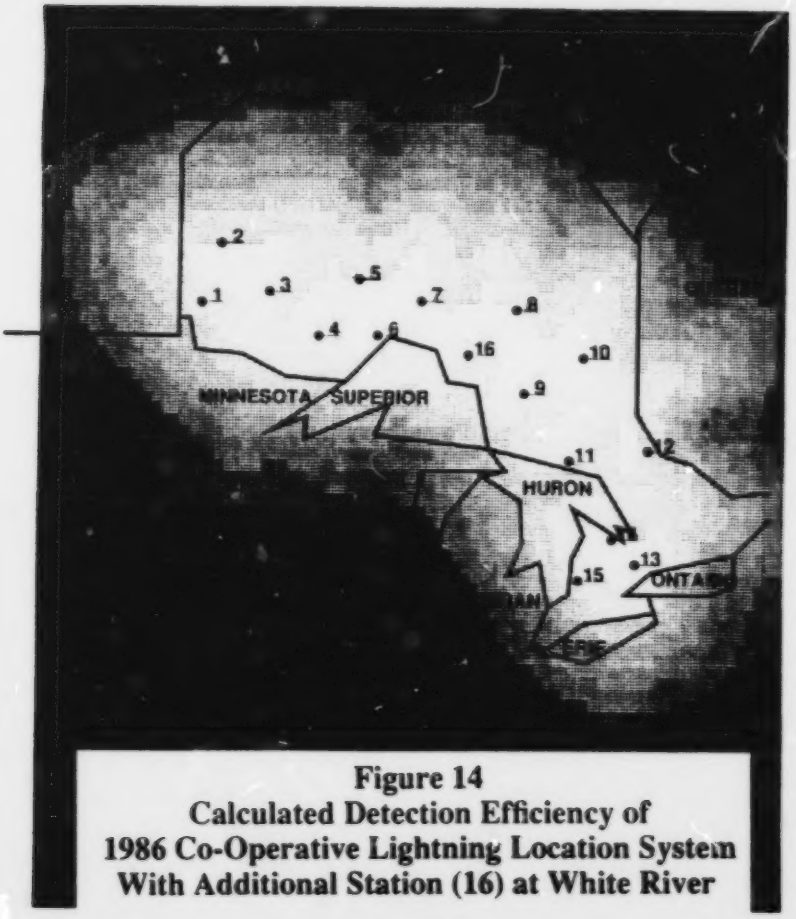

Figure 14
Calculated Detection Efficiency of
1986 Co-Operative Lightning Location System
With Additional Station (16) at White River

6.0 *RECOMMENDATIONS*

Ontario Hydro should continue to operate its existing DF sites in co-operation with the Ministry of Natural Resources. If improved detection efficiency and accuracy are required for tracking storms moving into southern Ontario, a third DF site should be added around Simcoe, Ontario.

Ontario Hydro should explore other internal uses of the real-time lightning data. Dispatch of line crews and verification of lightning failures are two potential applications.

Since the LLP DF equipment has proven to be a useful operational tool for power system management, the cost and control of the equipment should be transferred from the Research Division to PSOD in 1988.

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